Pyrolysis Heater

Background of the Invention

The present invention relates to a heater for the pyrolysis of hydrocarbons and particularly to a heater for the steam cracking of paraffins to produce olefins. In particular, the invention relates to a firing arrangement to prevent flame rollover and impingement on the process coils most particularly for staged combustion for low NO_x production.

The steam cracking or pyrolysis of hydrocarbons for the production of olefins is almost exclusively carried out in tubular coils located in fired heaters. The pyrolysis process is considered to be the heart of an olefin plant and has a significant influence on the economics of the overall plant.

The hydrocarbon feedstock may be any one of the wide variety of typical cracking feedstocks such as methane, ethane, propane, butane, mixtures of these gases, naphthas, gas oils, etc. The product stream contains a variety of components the concentration of which are dependent in part upon the feed selected. In the conventional pyrolysis process, vaporized feedstock is fed together with dilution steam to a tubular reactor located within the fired heater. The quantity of dilution steam required is dependent upon the feedstock selected; lighter feedstocks such as ethane require lower steam (0.2 lb./lb. feed), while heavier feedstocks such as naphtha and gas oils require steam/feed ratios of 0.5 to 1.0. The dilution steam has the dual function of lowering the partial pressure of the hydrocarbon and reducing the carburization rate of the pyrolysis coils.

In a typical pyrolysis process, the steam/feed mixture is preheated to a temperature just below the onset of the cracking reaction, typically 650° C. This preheat occurs in the convection section of the heater. The mix then passes to the radiant section where

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the pyrolysis reactions occur. Generally the residence time in the pyrolysis coil is in the range of 0.2 to 0.4 seconds and outlet temperatures for the reaction are on the order of 700° to $900^{\circ}C$. The reactions that result in the transformation of saturated hydrocarbons to olefins are highly endothermic thus requiring high levels of heat input. This heat input must occur at the elevated reaction temperatures. It is generally recognized in the industry that for most feedstocks, and especially for heavier feedstocks such as naphtha, shorter residence times will lead to higher selectivity to ethylene and propylene since secondary degradation reactions will be reduced. Further it is recognized that the lower the partial pressure of the hydrocarbon within the reaction environment, the higher the selectivity.

The flue gas temperatures in the radiant section of the fired heater are typically above 1,100°C. In a conventional design, approximately 32% to 40% of the heat fired as fuel into the heater is transferred into the coils in the radiant section. The balance of the heat is recovered in the convection section either as feed preheat or as steam generation. Given the limitation of small tube volume to achieve short residence times and the high temperatures of the process, heat transfer into the reaction tube is difficult. High heat fluxes are used and the operating tube metal temperatures are close to the mechanical limits for even exotic metallurgies. In most cases, the allowable maximum tube metal temperatures limit the extent to which residence time can be reduced as a result of a combination of higher process temperatures required at the coil outlet and the reduced tube length (hence tube surface area) which results in higher flux and thus higher tube metal temperatures. The exotic metal reaction tubes located in the radiant section of the cracking heater represent a substantial portion of the cost of the heater so it is important that they be utilized fully. Utilization is

defined as operating at as high and as uniform a heat flux and metal temperature as possible consistent with the design objectives of the heater. This will minimize the number and length of the tubes and the resulting total metal required for a given pyrolysis capacity.

In the design of ethylene cracking heaters, the process coils are suspended between two planes of firing. In the majority of cracking furnaces, at least a portion of the heat is supplied by hearth or floor burners that are installed on the floor of the firebox. Fuel and air are injected vertically into the firebox from the burners up along the walls and combustion occurs within the firebox in an essentially vertical direction up the walls. In a properly designed system, all of the combustion takes place in this vertical direction against the wall. The balance of the heat is supplied by burners located in the vertical walls and designed to fire radially along the vertical wall.

Typically a plurality of both hearth (floor) burners and wall burners are used to heat the wall which re-radiates that heat to the process coil. The flow of combusting gases in these heaters is essentially vertically up along the wall. This vertical flow results in a recirculation zone in which at some height above the hearth, the gas moves toward the coil plane, flows in a downward direction along the coil plane and then re-enters the vertical burner air flow. This recirculation pattern satisfies the momentum balance at the burners.

While combustion is taking place within this vertical flow of gases, it is desired to keep the combusting gases or flames against the wall and complete the combustion prior to reaching the top of the recirculation zone. This avoids "flame rollover" where the flame turns inwardly toward the centrally located vertical process coil tube-bank through which the process fluid flows. A flame is defined as a flow of gases that are still undergoing combustion reactions and is distinct from

the hot gases wherein the combustion has been completed. . While combustion is taking place, the combusting gases have higher temperatures. This heat is transferred to the fully combusted gases (flue gases) also within the box and ultimately to the process coils. If a "flame" contacts the process coil, higher than desired heat flux to the tubes and higher than desired tube metal temperatures can result. This in turn will lead to higher rates of coking (over-reaction) inside the tube at that point and limit the run-length or it will lead to carburization of the coil and mechanical failure at that point. Either way, it is not a desirable result. Therefore, the burners must be designed such that the combustion is finished prior to reaching the top of the recirculation or vortex zone.

In general, prior art burners were able to keep the combustion against the wall by imparting a vertical velocity to the airflow and initiating the combustion inside the burner throat. This created a vertical acceleration that allowed the combustion to be completed prior to the flame rolling over toward the coil plane and into the recirculation pattern. However, that was not always true and is not generally true for the new lower NO_x combustion type burners. In these low NO_x burners, the combustion is staged and purposely moved outside the main burner throat area. The main burners are fired with all of the air required but with a reduced or lean fuel flow. The additional fuel required is then injected separately into the burning mixture. This staged or delayed combustion results in lower maximum flame temperatures and reduced NO_x production. There is also less intense vertical momentum being imparted by the staged combustion. In many cases as a result of fuel staging, the combustion is not completed by the top of the recirculation zone. Further, as a result of the lower vertical momentum, the recirculation zone is located lower in the heater. Thus the combination

of slower combustion and lower recirculation zone height lead to flame rollover and the severe negative consequences on the process coil.

Summary of the Invention

The present invention relates to pyrolysis heaters, particularly for the cracking of hydrocarbons for the production of olefins, with a burner arrangement in the firebox including fuel injection ports to straighten the vertical flame and prevent flame rollover. In particular, the invention involves the introduction of a portion of the fuel supply along the walls of the heater at locations above the main burners and between the walls and the main burner flame.

Brief Description of the Drawings

Figure 1 is a simplified vertical cross-section representation of a typical pyrolysis heater.

Figure 2 is a cross section of a conventional hearth burner of the prior art.

Figure 3 is a diagram of a typical flow pattern within a firebox of a prior art pyrolysis heater having hearth burners.

Figure 4 is a perspective view of a portion of a pyrolysis heater in the region of the hearth burners illustrating a typical low NO_x burner.

Figure 5 is a diagram of the flow pattern within the firebox for the low NO_x burner of Figure 4.

Figure 6 shows isotherm lines for a low NO_x burner as in Figure 4.

Figure 7 is a perspective view similar to Figure 4 but incorporating the wall stabilizing fuel gas tips of the present invention.

Figure 8 is a diagram of the flow pattern within the firebox for the present invention.

Figure 9 shows isotherm lines for the present invention.

Description of the Prior Art and Preferred Embodiments of the Invention

Before describing the details of the preferred embodiments of the present invention, a typical prior art pyrolysis heater will be described. Figure 1 shows a cross section of such a prior art heater. This heater has a radiant heating zone 14 and a convection heating zone 16. Located in the convection heating zone 16 are the heat exchange surfaces 18 and 20 which in this case are illustrated for preheating the hydrocarbon feed 22. This zone may also contain heat exchange surface for producing steam. The preheated feed from the convection zone is fed at 24 to the heating coil generally designated 26 located in the radiant heating zone 14. The cracked product from the heating coil 26 exits at 30.

The radiant heating zone 14 comprises walls designated 32 and 34 and the floor or hearth 36. Mounted on the floor against the walls are the vertically firing main or hearth burners generally designated 38. These burners 38 are spaced along the wall. The size of a burner is determined by the individual burner firing capacity and the number of burners determined by the total fired duty required. A typical hearth burner 38 is illustrated in cross section in Figure 2 and consists of a burner tile 40 on the hearth 36 against the wall 32 through which the main combustion air and the majority of the fuel enter the heater. Each of these burners 38 contains one or more openings 42 for the main combustion air and one or more primary fuel nozzles 44 for the fuel. In addition, there may be a spoiler to create turbulence and allow the flame to remain in the tile (not shown). There may be additional fuel nozzles 46 located outside the tile but the majority of fuel is injected into the air stream within the confines of the tile. This promotes strong vertical

combustion. In addition to the hearth burners, the wall burners 49 in the upper portion of the firebox may be included. These are radiant-type burners designed to produce flat flame patterns which are spread across the walls to avoid flame impingement on the coil tubes.

Figure 3 illustrates the flame envelopes or patterns and the flue gas flow patterns inside the prior art cracking heater of Figure 1. The flames 50 and the hot flue gases flow basically straight up from the burners 38 along the walls 32 and 34 and the combustion is completed before it reaches the recirculation zone 52. A downdraft 54 of some of the hot flue gases runs along the cooler process coils 26 in the center and splits at the bottom and feeds back into the burners. Driving forces include high-velocity fuel jets, infiltrated burner air streams and buoyancy. This twin vortex pattern is well organized and efficient, because all of the hearth burners work in concert and fire essentially vertically with no horizontal component.

As a further description of prior art, Figure 4 is a perspective view of one version of a low NO_x burner arrangement 56 for a pyrolysis heater. This low NO_x burner arrangement comprises a burner tile 58 which in this case houses four main or primary burners illustrated by the primary burner ports 60. The burner tile 58 is a ceramic housing containing the burner ports which are supplied with the air and fuel from below the heater. Optionally, the burner tile 58 includes a portion 62 extending upwardly along the wall 32. This extended portion 62 serves as a flame holder or stabilizer.

All of the combustion air and the primary portion of the fuel gas are discharged into the firebox through the primary burner ports 60. There may also be additional primary fuel gas nozzles 64 where another small portion of primary fuel gas is introduced and mixed with the air and burned to stabilize the flame produced in the primary combustion

zone. The quantity of primary fuel is less than the prior art case and is only sufficient to raise the temperature of the incoming stream to a level that will support combustion outside the tile. This combustion zone is air rich and thus the combustion temperature is less than the case where a close to stoichiometric fuel air mixture is used in the primary zone. The lower temperature results in lower NO_x production. The remaining fuel gas is introduced into the firebox by way of the secondary fuel gas nozzles 66. The fuel gas discharged from the secondary fuel gas nozzles 66 is injected at such an angle that it mixes with primary air/fuel mixture and with cooled recirculating flue gases 54 at some distance above the tile 58 to form a fuel-air mixture diluted by those flue gases. The combustion of this secondary fuel occurs at the outside of the primary air/fuel combustion zone. A typical example of the distribution of the fuel for such low NO_x burners would be 40% to the primary burners 60, 57% to the secondary fuel gas nozzles 66 and 3% to the additional primary fuel gas nozzles 64. Merely as one specific example of a low NO_x burner arrangement, reference is made to U.S. Patent Application Publication No. US 2002/0064740 dated May 30, 2002. There are other design possibilities including simply shifting fuel from inside the tile to outside the tile in more conventional designs in order to achieve this combustion staging and thus reduced NO_x.

Figure 5 illustrates the flame patterns and the flue gas flow patterns inside of a prior art cracking heater with low NO_x burners such as illustrated in Figure 4. It can be seen that the flames 50 now extend further up into the heater due to the staged combustion and that there is rollover of the flames toward the heating coil 26. The majority of the combustion occurs outside of the tile. The acceleration of the combustion has created a lower density region on the side of the flame toward the heating coil that draws the flame toward the coil. Also, by

pulling the fuel away from the primary burner ports 60 out to the secondary fuel gas nozzles 66, a colder zone is created at the wall. This colder zone has a higher density and hydrodynamically acts to push the lower density flame away from the wall toward the coil. This Figure 4 also shows that the recirculation zone 52 has moved down. The result is that the heating coil 26 is at risk for over heating. Figure 6 shows the isothermal temperature lines of the center plane of a low NO_x burner with flame rollover. It can be seen that the temperature in the region of the coil 26 reaches well above 1600K. This high temperature creates heat transfer to the coil that can result in a coil metal temperature that exceeds 1350°K that is a typical maximum allowable metal temperature for the tubes in the coil in order to avoid failure.

The present invention is illustrated in Figure 7 which shows a hearth burner 56 which is a low NO_x burner as in Figure 4. Added to the firebox are the fuel gas injection, wall stabilizing tips 68 which fire fuel only (no air) and fire generally upward. These wall stabilizing fuel gas injection tips are located from one to ten feet and preferably about three feet above the burner tile 58. The fuel for these wall stabilizing fuel gas injection tips is preferably taken from the fuel that would normally be supplied to the secondary fuel gas nozzles 66 and is in the range of 5% to 30% and preferably about 15% of the total fuel gas feed. Each of these tips can contain a multiplicity of fuel injection orifices. A typical example of the fuel distribution would be 40% to the primary burners 60, 42% to the secondary fuel gas nozzles 66, 3% to the additional primary fuel gas nozzles 64 and 15% to the wall stabilizing fuel gas tips.

The effect of the wall stabilizing fuel gas tips on the combustion process is illustrated in Figure 8. The flames 50 are now much straighter and vertical than shown in Figure 5 and are pulled toward the

walls. The combusting zone at the wall created by these fuel jets is clearly visible. Also, the recirculation zone 52 has now moved up on the heater. By injecting the fuel above the burner tile and directly along the wall, the vertical combustion can be increased while maintaining the staging effect to reduce NO_x. This combustion also creates a low-pressure zone at the wall that effectively pulls the flame toward the wall. Figure 9 shows the center cut temperature isotherms. The high temperatures are now off the coil plane and pulled to the wall. The temperatures in the vicinity of the coil plane are now on the order of 1450K. This compares to the 1650-1850K temperatures in the case without wall stabilizing combustion. By reducing the temperatures at the coil plane, coil fouling and overheating can be dramatically reduced.

The following table lists the calculated maximum metal temperatures (in °F) for various tubes in a coil for prior art conventional burners (Design A), for prior art low NO_x burners (Design B), and for two different configurations of low NO_x burners with wall stabilizing fuel gas tips according to the present invention (Designs C and D). These temperatures represent the highest temperature anywhere along the length of the tube.

	Tube No.	Design A	Design B	Design C	Design D
Inlet Pass	t-1-1	1964	1988	1933	1921
	t-1-2	1894	1955	1901	1888
	t-2-1	1935	1957	1894	1882
	t-2-2	1893	1958	1891	1880
	t-3-1	1892	1960	1890	1880
	t-3-2	1890	1957	1885	1876
	t-4-1	1912	1980	1920	1913
	t-4-2	1886	1945	1891	1884
	t-5-1	1883	1992	1928	1921
	t-5-2	1883	1947	1886	1880
	t-6-1	1883	1950	1888	1881
	t-6-2	1881	1948	1885	1877
	Avg.	**1899**	**1961**	**1899**	**1890**
Outlet Pass	t-1	1842	1902	1846	1839
	t-2	1850	1905	1851	1844
	t-3	1856	1900	1854	1846
	t-4	1887	1897	1842	1836
	t-5	1894	1896	1846	1839
	t-6	1909	1903	1856	1845
	Avg.	**1873**	**1900**	**1849**	**1842**

From the temperatures, it is clear that the present invention reduces the tube metal temperatures (Designs C and D) as compared to the tube metal temperatures for a conventional low NO_x burner (Design B). In many cases, the temperatures are even lower than the basic prior art (Design A).

In cracking heaters, the rate of fouling (coking) is set by the metal temperature and its influence on the coking reactions that occur within the inner film of the process coil. The lower the metal temperature, the lower the rates of coking. The coke formed on the inner surface of the coil creates a thermal resistance to heat transfer. In order for the same process heat input to be obtained as the coil fouls, furnace firing must

increase and outside metal temperature must increase to compensate for the resistance of the coke layer.

With the design of the invention, the lower temperature results in a lower fouling rate and thus the rate that the firing must be increased to compensate is lower. In addition, the metallurgy of the cracking coils defined a fixed limit on maximum temperature at any one location along the coil in order to avoid tube failure. By utilizing the invention not only is the rate of fouling reduced, but the allowable temperature increase to the fixed limit is increased. This leads to a longer cycle length for the cracking heater and improved economic performance.

Although the invention has been described with reference to hearth burners which are typically considered to be low NO_x burners and to certain low NO_x burner arrangements and details, the present invention is not limited to such burners or their arrangements or details. The invention covers any combination of hearth burners and wall stabilizing fuel gas tips where the hearth burners are fired lean with all of the primary combustion air but with less than the stoichiometric quantity of fuel and where the remaining fuel is fired via the wall stabilizing fuel gas tips located on the walls above the hearth burners. The hearth burners can be located in any pattern along the walls of the radiant chamber with the important element being that the injection of the wall stabilizing fuel is only directly above the hearth burners.